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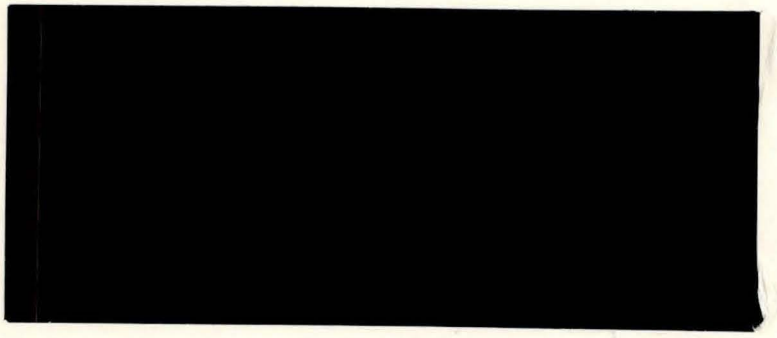

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FIRE CONTROL PLANNING, SIMULATION, AND THE FOREST SERVICE

by

Theodore G. Storey

NOTE: This Progress Report is the basis for a proposed publication in Government Data Systems journal. It has been carefully reviewed for technical accuracy by subject matter authorities. However, we anticipate the final published paper will receive substantial editorial changes in format and organization.

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ABSTRACT

Describes a system for evaluating forest fire control plans using computer simulation. It models and simulates the actual sequence of fire prevention, ignition, detection, initial attack, possible escape, control, and computes expected damage and cost. These simulation "modules" have been programmed and work individually many on data describing the planning unit stored in the database. When fully developed and exercised in the computer over fire seasons for a planning period of several years for alternate fire plans of men and equipment the system will provide the basis for objectively evaluating the net long-term consequences of various possible management decisions. Simulation results will also provide a rational basis for the preparation of budget requests and for allocation of funds appropriated. Individual modules can be exercised to answer specific operational questions. The simulation is currently programmed in FORTRAN IV for the IBM 360/91 computer and gives dollar damages and costs in tabular form as outputs. A large data base of spatial data by grid coordinates and other data is stored on disk. Time schedules and future plans are discussed.

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Introduction

The 210 million acres of National Forests in the United States experience 11,000 fires annually which burn over 203,000 acres causing 30 million dollars damage. Additional millions are spent to put these fires out and to finance the Forest Service's fire control organization, the largest and most extensive in the United States. Any improvements in the economy or efficiency of this organization could result in substantial savings as well as helping to preserve the environment. One possible area of improvement is fire planning--the rather complex procedure used by the Forest Service to determine the size and composition of fire organization needed to meet its fire control objectives. The Fire Management Systems Research Project, part of the research arm of the U. S. Forest Service, has been assigned this task as part of a continuing program to improve the fire control function.

Essentially, we are developing a computer simulation approach to model and simulate the entire sequence of prevention, fire occurrence, detection, spread, control, damage, and cost over time. The simulation run in the computer for a forest over a period of years for various fire plans of men and equipment, will reveal in a few minutes of computer time which plan has the most advantages and fewest drawbacks. That is it will be able to compare fire plans as if all plans had actually been in use simultaneously for several years. One output will be probable dollar damages and costs. Patterns of occurrence and potential escapes will also be shown.

Portions of the organization can also be simulated to answer "what if" questions of strategy and tactics at the local level. For example, what will happen if a certain fire station is relocated, or if crew size is increased or reduced a certain amount, a new fire access road is constructed, or a new fire prevention technique is adopted?

The Forest Service's fire planning system has been effective over the years in reducing numbers of fires and acres burned. However, at present it has neither of the capabilities mentioned above. The Office of Management and Budget now requires that agencies be able to demonstrate the productivity of alternate levels of program funding. This helps OMB determine levels of funding of agency programs and to choose which programs to fund. And rising resource values and costs of equipment and firefighter's wages require closer analysis or "finetuning" the organization assure that, at all levels, the best use is being made of each dollar appropriated. The evaluation model using computer simulation,when fully implemented, will provide all of these capabilities.

In our first year of operation we have completed the conceptual phase of the system. The component parts of the model have been identified, flowcharted, and data sources for a test Ranger District located. Currently we are working on the definition phase. All of the components or modules have been programmed using real data or interim manufactured data. Some modules can access the database for the entire District. The development phase in which individual components are programmed to work together on real data in the data base, and the implementation phase on actual Forests, lie ahead. We estimate that at least three more years will be required to complete the system. The study team consists of a multidisciplinary team of systems analysts, mathematicians, foresters, and programmers.

Fire Control Job

Forest fire control has several unique characteristics compared to city firefighting with which most readers probably are more familiar. About 90% of all forest fires in the United States are man-caused. Their occurrence, spread, and damage are more dependent on the weather than city fires.

Records show that on the average about 98 percent of the damage and acres burned on Forest Service-protected land result from about 5 percent of the fires. These fires occur on a relatively few high fire danger days during the year. But the timing and duration of the periods is not predictable closer than a few days ahead and, due to chance and other factors, fires may or may not occur during any given period. Prevention and detection efforts are intensified at these times. Thus the fire control job is largely a matter of recognizing the onset of bad fire conditions and having sufficient forces of men and equipment available to detect quickly and to hit fast and hard the fires occurring in these periods so as to keep them small. Putting it another way, fire suppression depends on the availability and proximity to the fire of control forces and on force productivity in relation to fuel and burning conditions. This activity is commonly referred to as initial attack.

But provision must also be made for expanding the organization to handle fires that do escape and become large. Conversely, it is prudent to reduce the strength of alert forces during easier weather conditions. Regular appropriations or funding supports the prevention, detection, and initial attack activities. When initial attack fails and the organization must be expanded, emergency forest firefighting (FFF) funds become available. FFF funds may also be used to increase preparedness in periods of high fire danger in advance of actual fire occurrence. A supplemental appropriation bill is passed by Congress each year to cover these expenditures.

Forest fire occurrence depends heavily on human activity and on the weather and condition of fuels. Subsequent spread depends on fuel, weather, and topography. Forest fire fuels are exposed to the weather and are strongly affected by precipitation and by small changes in temperature, humidity, and wind compared to urban fuels. Extended lack of rain or drought also causes larger diameter fuels to dry out and all fuels to burn more intensely adding to the fire problem. However, many of these relationships are not precisely known.

Most Forest Service lands are extensive and remote. This coupled with the limited total number of forces available and the wide variety of types of force and capabilities required makes the siting of fire stations, proper choice of force to the job, and efficient dispatch very important.

As our population grows, urbanization is spreading into forested areas. The future undoubtedly will see more commonality of city and wildland firefighting problems.

Fire Planning

Requirements

Forest Service fire planning is done to satisfy two basic needs (a) budgetary and (b) operational, including strategy and tactics.

For budgeting the system should identify benefits and costs associated with alternate fire plans so as to provide a rational basis and justification for budget proposals to Congress. In other words it should be capable of evaluating fire plans.

In addition, the planning system should provide the Forest Service Washington Office with a rational basis for allocating among Regions the fire funds appropriated to the Forest Service by Congress. It should give them the basis for placing the funds where they will do the most good. There are nine Regions and 153 Forests in the United States.

Operationally, fire planning is most useful at the lower levels of organization, the Forest and the Ranger District, to evaluate strategy and tactics. Considerable detail is necessary in order to evaluate small-scale changes in organization, for example relocating a fire station, replacing a handcrew with a pumper, or adopting a new design fire prevention sign. Although relatively small scale, such changes are extremely important in carrying out the fire control function on the fireground.

Current Procedure

The Forest Service's fire planning system starts with assembling a data base of all appropriate information. This includes fire danger ratings, fuels, access, risk of fire, values, constraints imposed by management decisions or by policy, etc. Data are prepared through field inventory, knowledge of the country, and compilations of statistical data. Then the planner analyzes all these data and, based on his judgment and experience prepares a fire plan. The plan lists the kind, amount, and location of resources proposed. It can also specify any fuel treatment measures, such as fuel breaks, which may be included as part of the protection package (Show and Kotock 1930, Hornby 1936, and Gisborne 1939).

General planning guidelines are issued by the Forest Service Washington Office (U. S. Forest Service 1969). Detailed procedures are written by each Region for the Forests to follow.

At present, however, the only way to test the efficacy of the plan is to implement it and then evaluate it in operation making changes as deficiences become evident. But this procedure may take years and is very expensive. Also, conditions are changing.

The Simulation Approach

A close approximation of the ideal technique of implementation and evaluation is possible through the use of computer simulation. A representation, or model, of the current situation can be developed. This model may be expressed in a form suitable for study with the use of a computer. It uses many of the same data used for fire planning. Various factors, representing proposed changes to the actual situation, are then tested in the model. The effects of the changes on the model are printed out by the computer and may then be evaluated to determine the consequences of the proposed plan or plans.

When the desirable plan of those proposed--that which contains the most probable benefits with the fewest probable drawbacks--has been determined through evaluation, it may then be implemented in the actual situation.

One of the unique advantages of simulation by computer is its ability to compress the time of occurrence of projected future events into brief intervals of present time. Thus simulation can be a positive factor in making decisions, by providing management with the ability to test and evaluate various plans long before making important commitments.

The development and use of computer has given impetus to the development and use of simulation. While many types of simulation have been theoretically possible for some time, their use has not been economical or practical until fairly recently.

Most large simulation models are possible because of the high speed data manipulation and computation capabilities of the computer. Two important factors have contributed to the ever increasing use of computers for simulation--experience and easier methods of model making. With experience comes confidence; enough simulation has been performed to assure users that simulation is both a valuable and valid aid in the making of decisions. (Hillier and Lieberman 1967, Mize and Cox 1968, Ockene 1970, Burling 1970, Gluck, et al 1970).

Easier ways of model making have been developed as the use of simulation has grown.

The accuracy of computers is equally important to the simulation. Computers can accurately handle the processing, thus insuring the correctness of the output for evaluation.

The Simulation Model

Information Flow

The basic information flow in the simulation model is shown in Figure 1. The fire plan to be evaluated consists primarily of programs and plans in the five areas shown at the left. The six large blocks or "modules" in left center represent the simulation, per se. The database contains and supplies all of the information and data needed by the modules. The administrative decision block reflects the fact that management makes the final decision or choice among alternatives evaluated by the computer simulation.

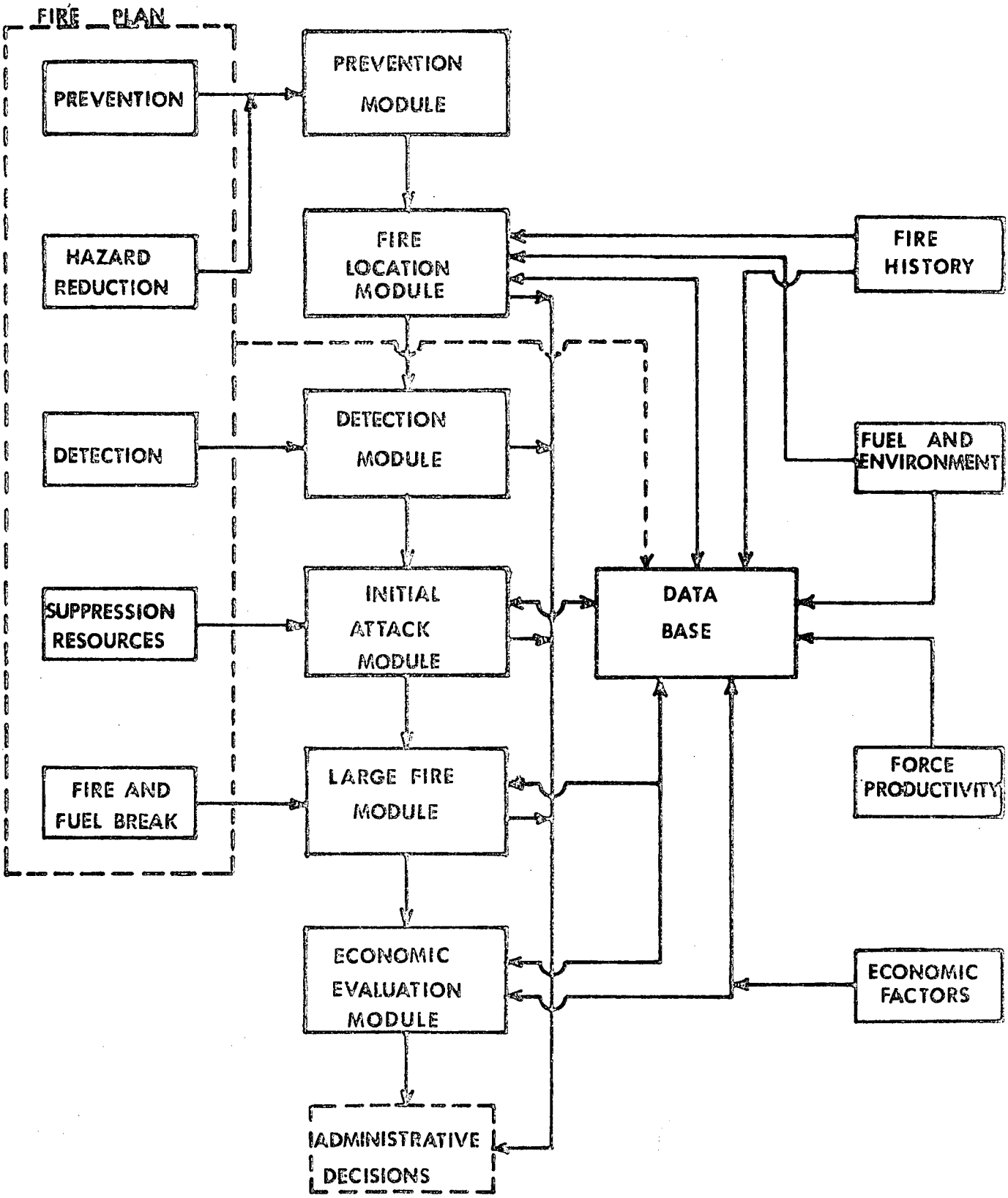


Figure 1.-- Fire planning evaluation simulation model

The remaining blocks, on the right, represent other data and functions which are involved in developing the simulation and supplying data to the database. In general, the simulation modules follow the sequence of events in actual fire situations, i.e., fire start (including the effects of prevention and hazard reduction), detection, initial attack, possible escape to large fire status, ultimate control, and evaluation including expected damage incurred and cost of suppression.

The simulation includes each of these modules as an independent functional entity. The approach was to design an overall model framework into which could be fitted the best currently available "present state-of-the-art" information and relationships for the various functional areas in the initial design. It was essential, we felt, to do this so that improved data, advances in the state of knowledge, and technological developments could readily be incorporated as they became available.

For the simulation a planning unit is divided into a number of cells of a specified size, presently one mile square. Fuel type, damage potential, weather zone, slope, and other measures of condition in each cell are stored in the computer database and referenced to their map or ground location. The transportation network, fire equipment inventory, and location obtained from the fire plan also are stored and referenced to their map location. Non-map items such as dispatch decision rules and production functions also are stored in the database.

We are using data from the Payson Ranger District, Tonto National Forest, Arizona to develop the initial design. Data for a few items were manufactured pending the Forest supplying the necessary actual data. Later stages will include the whole Forest and test Forests in other Regions. All data will be actual data about the Forest.

The current version of the simulation considers single fire occurrences. Later versions will include the multiple fire case i.e., two or more fires occurring simultaneously. Multiple fires are primarily a problem in initial attack and large fire suppression taxing firefighting resources.

Prevention Module

This module specifies for a given fire plan the effect of prevention measures on potential ignitions generated by the Fire Location Module. Together they determine which potential ignitions actually ignite or are prevented.

Fire prevention measures include education, hazard reduction or fuel treatment to reduce the chances of a fire starting, and law enforcement. Only the second measure affects lightning fires and the effect is very small. However, research is working on ways to prevent lightning strikes through weather modification. All three measures are effective in varying degrees against man-caused fires, although with the present state of the art of fire prevention, it is rather difficult to assess their effects. Probably it will never be possible to prevent all fires. Separate submodules to model these conditions still need to be developed.

In the present definition stage of model development all prevention measures are lumped. Their combined effect for a particular fire plan is entered as a flat percent reduction or increase in number of potential ignitions generated by the next module, fire location. Estimates are based on the expert opinion of experienced local fire managers of how much and in what direction each candidate plan will affect potential ignitions compared to the "current" plan. The current plan is the average prevention effort in effect over the period of record used to develop the fire location module and generate potential fires for the simulation. As ongoing prevention research yield results, these will be incorporated to improve the simulation.

Fire Location Module

This module produces the location and description of ignitions or fire starts and fires prevented in the planning unit for the simulated planning period, Figure 2. Fire starts are passed to the Detection Module, their locations and descriptions or parameters directly to the Initial Attack Module. Fires prevented are listed for the fire planner. Separate submodules for lightning fires, submodule A, and man-caused fires, submodule B, reflects the fact that their occurrence in space and time are different in nature.

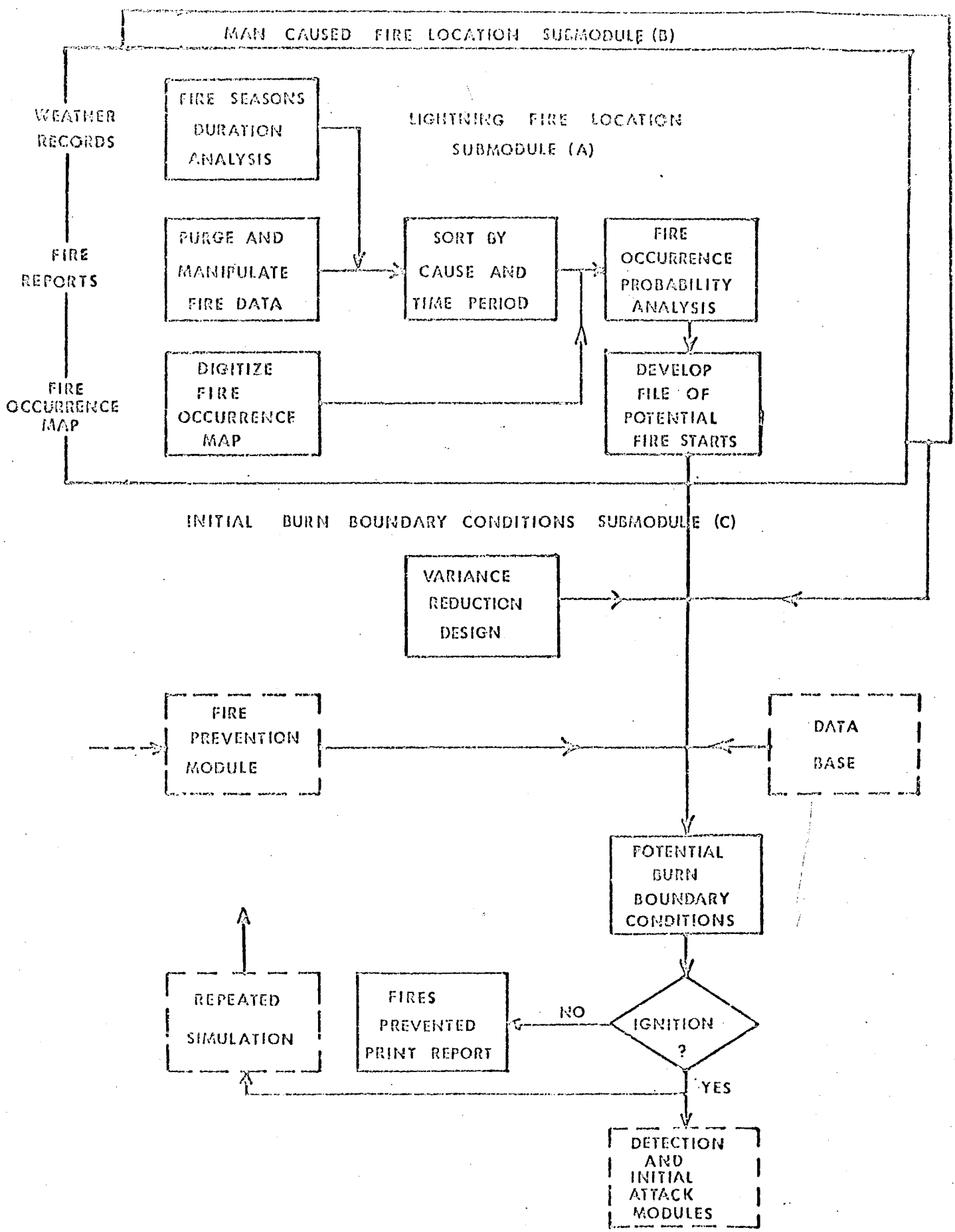


Figure 2.-- Fire location module and submodules

Submodule A analyzes records of lightning fires to develop a probability distribution of lightning fire occurrence for each cell of the planning unit. Then Monte Carlo methods are applied to develop a file of potential fire starts for the planning unit for each fire season (Sasieni et. al. 1959).

Submodule B serves the same purpose for man-caused fires. However, the detailed procedures are not completed at this time. Eventually, files of fire starts from both modules will be passed to submodule C, initial burn boundary conditions. Submodule C also is presently in the conceptual phase. Its major function is to determine, for the potential ignitions supplied by submodules A and B and the prevention module which ones will actually ignite or not ignite, Figure 2. This depends on the environmental conditions of fuel, weather, and topography in the vicinity and on fire prevention measures taken in the planning unit. Environmental conditions for each cell are obtained from the general database.

More specifically, a Monte Carlo procedure is used to generate, from the population parameters for a given cell a unique set of burning condition variables for the potential fire. Then the effects of fire prevention measures are examined and a decision made whether any of these measures did in fact keep a fire from actually starting. If the potential fire start is prevented, the fire is listed for the planner. If there is a fire start, the set uf unique initial burning conditions are then passed on to the detection module for analysis.

The above discussion of submodule (C) reflects our present concept of how it works. The steps shown are subject to change as we progress to the definition phase. All we can currently do is generate a potential lightning fire in a reasonable approximation of the conditions existing in a given planning unit, estimate whether it will be prevented or will ignite and pass the location and description of the ignition on to the detection module and to the initial attack module for analysis.

Detection Module

All fires are eventually detected or go out by themselves, the effect of delayed detection being a larger fire to fight, on the average. Currently the size at detection of each fire produced by the Fire Location Module is determined in the Detection Module, Figure 2. Its location and parameters of fuel type, topography, weather, and other factors are passed by the fire location module directly to the initial attack module without going through detection.

The detection subprogram uses a Monte Carlo process to select a fire size from a probability distribution of fire size at detection. At present the effect of different detection systems or detection plans must be estimated subjectively based on expert opinion. The size selected is passed to the Initial Attack Module.

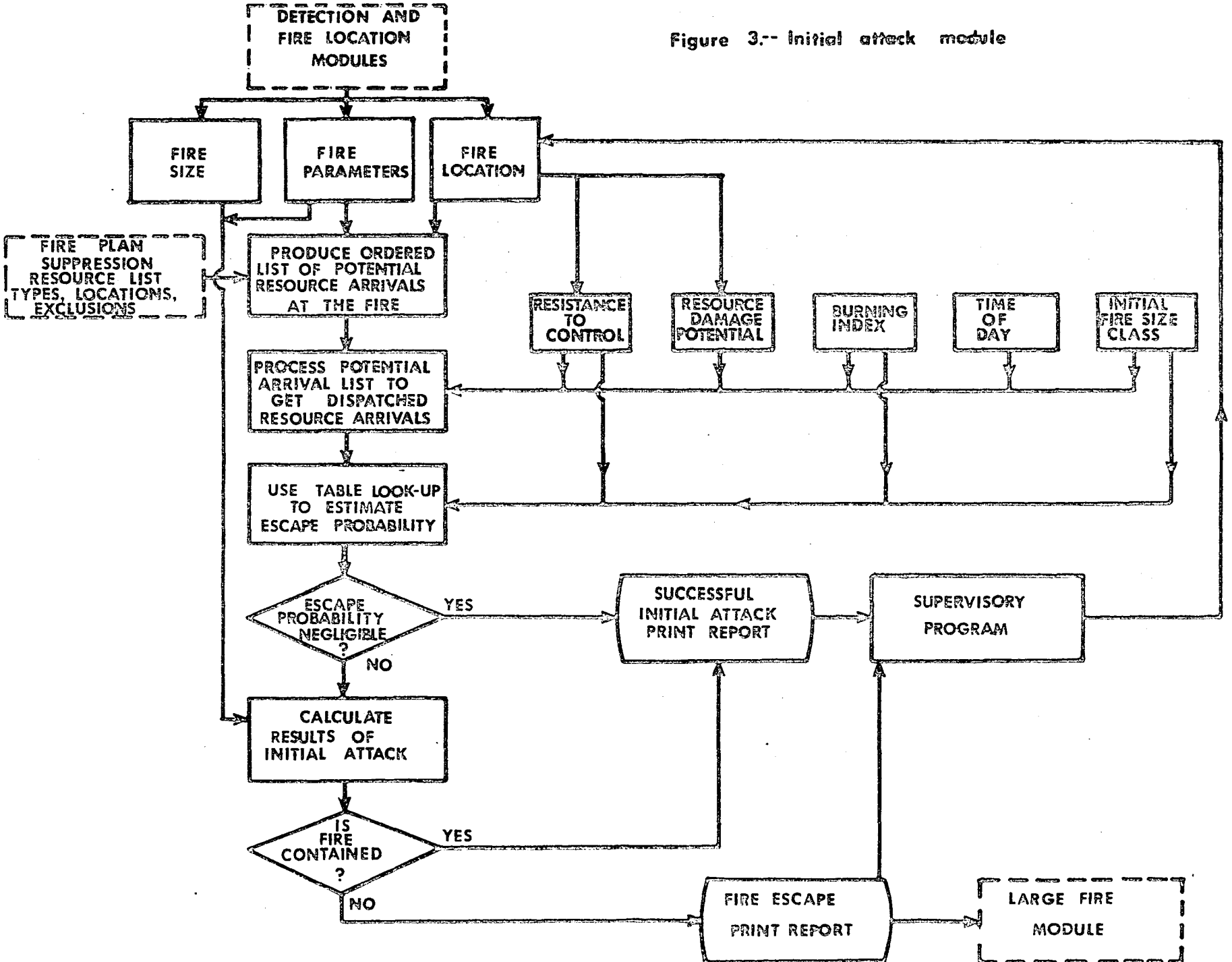
Work is underway elsewhere on a more complete detection analysis (Kourtz and O'Regan 1968). This is a major effort and results will not be available for some time. When they are, they will be substituted for the present detection algorithm in the evaluation model.

Initial Attack Module

Each fire passed by the Detection Module and by the Fire Location Module is handled independently by the current version of the Initial Attack Module, Figure 3, The detection module determines size, the fire location module passes location and fire parameters.

First, a sequence of potential arrivals at the fire of all nonexcluded resources is generated. Times of arrival and identities of the units involved are recorded. Resources include hand crews, pumpers, tractor plows, helicopters and fixed wing aircraft depending on what is available and suitable in the given situation.

Figure 3.-- Initial attack module



Decision rules for dispatching are then applied to the sequence of possible arrivals to sort out those which constitute a valid dispatching sequence. It is assumed that dispatches are made relative to three basic considerations: (1) fire locations, (2) the severity of the fire problem, and (3) resource availability. Parameters which reflect these considerations are used to derive a "prescribed" nominal attack strength. This nominal attack is further modified by the "resource damage potential" of the fire to arrive at a final dispatch strength requirement. The possible dispatches are then matched against this requirement until the requirement is satisfied or met as nearly as possible. Dispatch rules and equipment inventories are subroutines. Resource damage potential, environmental data, and other map related items are stored in the database.

To avoid spending computation time on easy fire problems, a table look-up procedure is used to dispose of these routine fires. Tables giving time for containment and final area versus initial area have been pre-calculated. A reference to these tables will identify the large percentage of fire starts which pose no difficult initial attack problems, Figure 3. A report of these fires is printed for the fire planner. They are not passed to the economic evaluation module because the cost of suppressing them is included in the cost of the base fire plan. And since they are small, the damage they do is considered negligible.

However, the benefits from having kept these fires from becoming large will reflect to the advantage of the fire plan in use at the time in the form of lower total expected dollar loss and impact over the simulation period. The fires which are doubtful, using the simple test, are passed on to the more complete initial attack calculation procedure.

The main initial attack program includes, in addition to the dispatching subroutine, a fire spread model and a suppression force productivity subroutine.

Fire Spread Model--a modified elliptical model is being used initially to represent early fire spread, Figure 3. Three parameters are required to specify an elliptical-shaped fire, (1) initial size, such as area at discovery; (2) shape, such as eccentricity or length to width ratio; and (3) rate, such as rate of forward spread.

There is a considerable body of literature which contains data relating the parameters listed above, or their equivalents, to fuel, topography, and weather factors. Data on fuel and topography in the vicinity of the fire are obtained from the general computer database for the forest under consideration. Weather factors are obtained from historical weather and Fire Danger Rating records.

Suppression Force Productivity - Suppression tactics are assumed to be aimed at suppression of a fire along its perimeter, so that rates of line construction or rates of perimeter suppression are the products of suppression resources. Retardant drops from air tankers produce temporary barriers which the fire has some probability of penetrating. Also the fire may bypass these barriers if ground crew activity cannot make the necessary tie-ins.

It is necessary to secure the help of Forests and Regions in formulating realistic tactical models and force productivity functions for their particular areas. Locations by map coordinates of areas where certain forces cannot be used, such as terrain too steep for bulldozers, are stored in the database.

Fire successfully caught by initial attack are listed by the computer for the fire planner. Those fires that escape also are listed and in addition are passed on to the Large Fire Module, Figures 1 and 3. Then the simulation is repeated.

Large Fire Module

When the Initial Attack Module decides which starts have escaped, it transfers their location and fire danger index to the Large Fire Module, Figure 1. This module, in turn, determines the final size, shape, and intensity of these escape fires which are then passed on to the Economic Evaluation Module.

The large fire module first chooses the final fire size stochastically from the appropriate cumulative probability distribution curve of historical final sizes for a given fire danger index.

If the final size exceeds one grid cell, the program obtains the probability of spread to each neighboring cell from the data base. From these transitional spread probabilities, grid cells are chosen randomly, cell by cell, to make up the final area (Clark 1965, Drewett 1969). The spread probabilities have been pre-computed using topographic data, forest fuel type, weather records, and a table of fire spread rates.[1/]

[1/] Interim fire spread rates provided by Mr. H. E. Anderson, Northern Forest Fire Laboratory, Missoula, Montana, December 4, 1970.

The final size may be truncated, i.e. not reach the pre-determined final size, if "barriers" such as fresh burns or fire breaks are introduced for evaluation by the planning simulation module, Figure 1. The success or failure of such barriers is stochastically evaluated from pre-assigned probabilities of their success. Thus a fire greater than one grid cell in size is shaped by topological, fuel and wind factors and the final size responds to fire planning alternatives.

Finally, a summary is printed by the computer for the fire planner showing the number of fires and acres burned by fire size class and total acres burned during the simulation period. In addition, the map locations of the cells burned by each fire and fire intensity are passed to the economic evaluation module for analysis.

The chief difficulty with this approach is the dearth of data on the very large fires. Because they occur only rarely, the shape of the probability distribution--especially the tails of the curve--is not well defined. Yet these fires produce a very large percent of the total damage.

In the future, when more is known about the spread of large fires and the influence of control forces, it may be possible to model large fire spread and control more predictively.

Economic Evaluation Module

The purpose of this module is to assess the economic and other consequences of the simulated results of alternate fire plans. This is the payoff of the entire simulation.

When the Large Fire Module has determined that a fire has reached its final size, the locations of the burned cells and the intensity of burn are transferred to the Economic Evaluation Module, Figure 4. This module, as a first step, determines three things for each fire, (1) dollar damages, additive over acreage and non-additive, (2) non-dollar damages, and (3) suppression costs. Each item is accumulated for all fires over the simulated planning period.

Second, the dollar damages, if any, associated with the overall patterns or clusters of fires in step no. 1 are determined. These damages are cumulated for the planning period and added to the cumulated dollar damages and suppression costs from step no. 1.

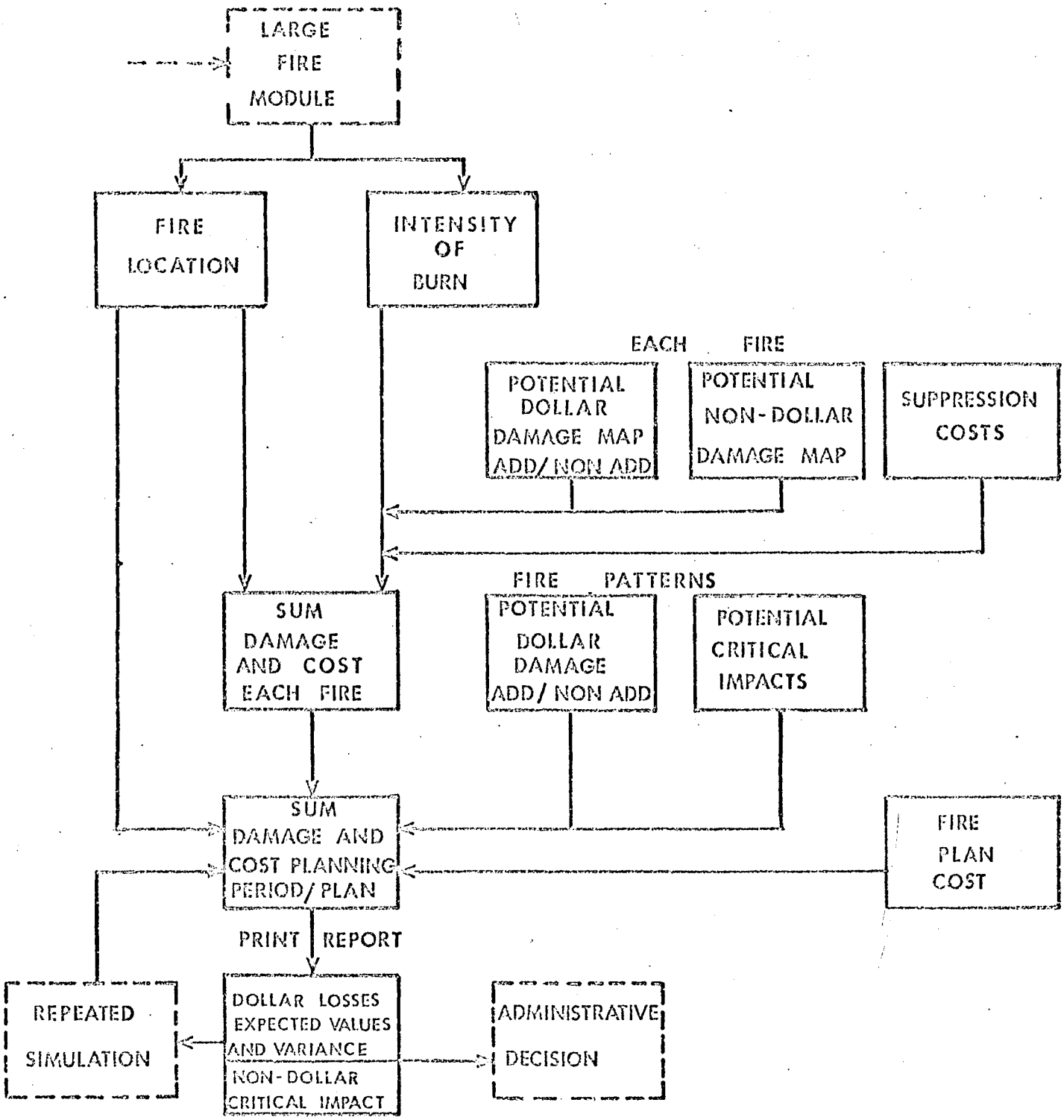


Figure 4.-- Economic evaluation module.

Third, the critical impacts of overall patterns of fires in repeated simulations over the planning period are determined, Figure 4. For example, several large fires concentrated in the geographical area supplying a particular lumber mill might cause the mill to cease operation and otherwise disrupt the local economy.

Finally, the expected value and variance of the dollar losses plus plan costs over repeated simulations are computed and printed out. This report provides information on net revenue productivity to the administrator who must choose between plans. However, this information must be weighed with the information on non-dollar damages of individual fires, step no. 1, and critical impacts of overall patterns of fires, step no. 3, as well as other factors, before final choices can be made. This information will be expressed in numbers or descriptive terms as appropriate.

Since much of the basic economic data needed to implement this module is not currently available, preliminary approaches will use historical averages of dollar damage and costs by size class of fire with some degree of stratification by geographic variables. Non-dollar critical impacts will be incorporated to illustrate their effect. No attempt will be made to work with non-additive or intensity-related damage in the immediate future. Efforts to develop the basic economic data needed are proceeding concurrently with model development.

Database and Computers

The simulation program presently is written in FORTRAN IV (G) language for the IBM 360/91 computer. Access is by a remote Data 100 terminal. The database is stored on disk and accessed by the mainline simulation and subroutines.

Inventory data were digitized from maps and other sources using hand coding and graphic coordinate digitizing. An invenstigation of faster and more economical methods for digitizing spatial data is proceeding concurrently. One promising system involves scanning miniature black and white photo negatives of colored maps of fuel types, value class, and other items with an automatic drum-type digitizing densitometer. Densities are recorded on magnetic tape by x, y coordinates. Densities corresponding to gray levels on the negative are converted in the computer to the appropriate resource codes and their locations to the appropriate map reference system. These data are stored on disk in the database.

Obtaining good data is one of the greatest problems we have had to face in developing the simulation. For example, fire reports have for many years recorded a variety of items of location, fire weather, fuels, topography, forces used, and damage. But we found that many needed items weren't recorded or, if recorded, did not meet our needs. Many records are unreliable. Steps are being taken to assure better records in the future.

Present Status

Experience to date indicates that our concept of a simulation model for evaluating fire plans is sound. Presently we are in the second or definition phase of model development. All modules have been programmed and work to some extent individually on partial data from one test ranger district. Some modules can access the data base of complete information. However, due to a variety of factors, mostly beyond our control, certain modules are further along than others. Factors include complexity of the variables and functions involved, status of basic theory and knowledge, and availability of data. The initial attack module, which deals with small fires, is farthest along; the prevention module the least. Because fires in initial attack are small, they are easier to study and measure and more is known of their spread and control. Large fires, on the other hand, have a third or vertical dimension and large scale weather and topographic effects play a greater role in determining their behavior. These factors are difficult to measure and their effects difficult to model.

Probably the prevention module is the least tractable of all to model. Most fires are man-caused and preventing them involves human motivation, attitudes, and education. The level of knowledge of these factors is rather low and difficult to quantify making prevention difficult to simulate. The economic evaluation module also poses some difficult problems. There is a lack of agreement among resource economists on basic theory and how to apply it. Also, evaluation procedures based on new economic theory may be at odds with current agency policy and objectives. Even if changes are indicated, certainly they cannot be implemented overnight.

In order to handle the complexity of the simulation and variety of factors included, we have adopted a CPM/PERT technique for scheduling work and reporting progress.

The current simulation is based on single fires. Multiple fire capability will be added as we gain experience with the single fire case and as concurrent basic research studies including simulation techniques yield results.

It should be recongized that computer simulation is not cheap. As a minimum, even when operational, hundreds of runs are necessary to satisfactorily simulate one fire season over the simulated planning period. However, the benefits clearly should outweigh the costs.

Future Development

The definition phase will continue until all modules are working individually on actual data in the data base for one ranger district. It is expected that this will take one year to accomplish. The third or development phase in which all modules are made to work together will follow. This phase will also require considerable verification time to test for sensitivity of output of the simulation to precision of measurement of variables. Verification will also involve checking outputs number of fires, size, damage, and costs for reasonableness, i.e. against the "real world". This will be done for the original test forest followed by tests on representative forests in other regions. Since certain modules are farther along than others, they will be completed sooner. Many of them are potentially useful by themselves to planners. There is no reason these modules cannot be implemented at least locally ahead of the complete simulation.

The final or implementation phase on all forests is expected to consume the fourth and final year. In a sense the simulation model will never be completed. Modules and programming will be periodically revised and improved as research yields results and as advances are made in computer software and hardware technology.

Although the simulation is being developed by the Forest Service, it models basic principles of fire behavior and suppression and should be applicable with minor modifications to any forest fire control organization. Portions of it should be applicable to urban fire control planning.

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